ISSN 1063-7737, Astronomy Letters, 2018, Vol. 44, No. 1, pp. 8–34. © Pleiades Publishing, Inc., 2018.
Published in Russian in Pis'ma v Astronomicheskii Zhurnal, 2018, Vol. 44, No. 1, pp. 4–37.

Stellar Mass—Halo Mass Relation and Star Formation Efficiency in High-Mass Halos*

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Received April 20, 2017

Abstract—We study relation between stellar mass and halo mass for high-mass halos using a sample of galaxy clusters with accurate measurements of stellar masses from optical and ifrared data and total masses from X-ray observations. We find that stellar mass of the brightest cluster galaxies (BCGs) scales as $M_{*,\rm BCG} \propto M_{500}^{\alpha_{\rm BCG}}$ with the best fit slope of $\alpha_{\rm BCG} \approx 0.4 \pm 0.1$. We measure scatter of $M_{*,\rm BCG}$ at a fixed M_{500} of ≈0.2 dex. We show that stellar mass-halo mass relations from abundance matching or halo modelling reported in recent studies underestimate masses of BCGs by a factor of ∼2−4. We argue that this is because these studies used stellar mass functions (SMF) based on photometry that severely underestimates the outer surface brightness profiles of massive galaxies. We show that $M_* - M$ relation derived using abundance matching with the recent SMF calibration by Bernardi et al. (2013) based on improved photometry is in a much better agreement with the relation we derive via direct calibration for observed clusters. The total stellar mass of galaxies correlates with total mass M_{500} with the slope of $\approx 0.6 \pm 0.1$ and scatter of 0.1 dex. This indicates that efficiency with which baryons are converted into stars decreases with increasing cluster mass. The low scatter is due to large contribution of satellite galaxies: the stellar mass in satellite galaxies correlates with M_{500} with scatter of ≈0.1 dex and best fit slope of $\alpha_{\rm sat} \approx 0.8 \pm 0.1$. We show that for a fixed choice of the initial mass function (IMF) total stellar fraction in clusters is only a factor of 3−5 lower than the peak stellar fraction reached in $M \approx 10^{12}\,M_\odot$ halos. The difference is only a factor of ∼1.5−3 if the IMF becomes progressively more bottom heavy with increasing mass in early type galaxies, as indicated by recent observational analyses. This means that the overall efficiency of star formation in massive halos is only moderately suppressed compared to L_* galaxies and is considerably less suppressed than previously thought. The larger normalization and slope of the $M_* - M$ relation derived in this study shows that feedback and associated suppression of star formation in massive halos should be weaker than assumed in most of the current semi-analytic models and simulations.

DOI: 10.1134/S1063773717120015

Keywords: *galaxy clusters, dark matter, stellar mass, star formation*

INTRODUCTION

In hierarchical Cold Dark Matter (CDM) models of structure formation, galaxies are thought to form via dissipative processes within potential wells of dark matter-dominated halos (White and Rees 1978; Fall and Efstathiou 1980; Blumenthal et al. 1982, 1984). Cooling leads to condensation of baryons towards the center of their parent halo (e.g., Rees and Ostriker 1977) where they reach conditions suitable for star formation. Understanding efficiency with which halos convert their baryons into stars is one of the central problems in modelling galaxy formation. Results of abundance matching of halo mass function to the stellar mass function of galaxies showed that this efficiency peaks at halo masses of $M \approx 10^{12}\,M_\odot$ but is quickly decreasing at both smaller and larger masses (e.g., Conroy and Wechsler 2009; Guo et al. 2010). Remarkably, this peak mass is almost independent of redshift (Yang et al. 2012; Behroozi et al. 2013a). Even at the peak of efficiency, observed masses of

*The article is published in the original.

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